

Modeling Open-Ocean Deep Convection

John Marshall, 54-1526, MIT, Cambridge, MA 02139

Phone: 617-253-9615; fax: 617-253-4464; Email: marshall@gyre.mit.edu

Award number: N00014-95-1-0967

LONG-TERM GOALS

To understand the convective process in the ocean, develop numerical models to study it, and so improve the representation of convection in ocean circulation models.

OBJECTIVE

To understand the relative importance of vertical mixing by convection and lateral advection by geostrophic eddies in setting the volume and properties of water-masses formed by intense winter storms blowing over the open ocean. The insights gained will inform and improve parametric representations of convection used in large-scale ocean models.

APPROACH

We are interpreting data gathered in the ONR Labrador Sea Convection Experiment, making use of process models of convection and a high-resolution model of the Labrador Sea developed at MIT.

We have developed non-hydrostatic, hydro-dynamical models exploiting parallel computational architectures and languages (see Marshall et al. [1997 a, b], Hill and Marshall [1996], Adcroft et al. [1997]) that are capable of explicitly resolving the convective scale in the ocean. The model has been used to study convection modified by rotation in idealized settings; these have led to much insight into the nature of the convective process, have provided input to the planning of the field program, and are helping in the interpretation of the measurements that have been taken.

WORK COMPLETED

The MIT model was configured in a realistic geometry appropriate for the Labrador Sea, and an ice model was embedded. The model was initialized with a hydrographic analysis making use of hydrographic sections taken in Autumn 1996 and driven by analyzed NCEP fields through the period of the field experiment. The output of the model is being used:

- to study the cycle of convection and restratification in the Labrador Sea;
- to help in the interpretation of the field observations.

Over the last year much effort was put in to the porting of our codes to the new generation of parallel machines based on commodity SMP's and the development of an adjoint to the new code.

RESULTS

Models of convection and ocean circulation developed at MIT, made possible by ONR's support, played a central role in the planning and execution of the field experiment conducted last winter. Using

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Modeling Open-Ocean Deep Convection				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

our limited-area model of the Labrador Sea, together with historical data, analyzed buoyancy fluxes heat fluxes and quasi-real-time temperature and salinity profiles from ALACE floats, we were able to predict three months ahead of time where to expect deep convection in the Labrador Sea. Based on those predictions the small-scale float array was deployed at a location that turned out to be exactly where deep convection down to 1500 m was observed during early March 1997 (see Marshall et al. and the Lab Sea group [1998]). Two papers were completed during this period (see [11] and [12] below).

IMPACT /APPLICATIONS

The research has had the following impacts:

- led to the development of numerical methods and highly optimized parallel code for solution of the Incompressible Navier Stokes equations in the highly irregular geometries typical of ocean basins and marginal seas (see publications [1], [2], [9], and [10]).
- applied maturing parallel architectures and languages to the numerical solution of the Navier Stokes equations.
- deepened our understanding of convection in the presence of rotation, and its role in the ocean circulation (see publications [3] to [8]; [13] to [16]).
- provided a theoretical and modeling context for the ONR 'Deep Convection' ARI in the Labrador Sea (see publication [17]).

TRANSITIONS

Our models and approaches are being used by an increasingly wide community, both at MIT and elsewhere. Our work on convection has led to numerous publications in the literature starting from the paradigms we have set out.

RELATED PROJECTS

1. The Labrador Sea Deep Convection Experiment
<http://www.ldeo.columbia.edu/~visbeck/labsea/labsea.html>
2. MIT AUV development program
http://seagrant.mit.edu/~auvlab/AUV_home.html

PUBLICATIONS

- [1] Adcroft, A.J., C.N. Hill, and J. Marshall. 1997: Representation of topography by shaved cells in a height coordinate ocean model, *M.W.R.* 125, 2293-2315.
- [2] Hill, C., and J. Marshall. 1996: Application of a Parallel Navier-Stokes Model to Ocean Circulation, *Proceedings of Parallel CFD '95*, Caltech.
- [3] Jones, H., and J. C. Marshall. 1993: Convection with rotation in a neutral ocean; a study of open-ocean deep convection, *J. Phys. Oceanogr.* 23, 1009-1039.

- [4] Jones, H., and J. Marshall. 1997: Restratification after deep convection, *J. Phys. Oceanogr.* 27, 2276-2287.
- [5] Klinger, B., and J. C. Marshall. 1995: Regimes and scaling laws for open-ocean deep convection, *Dyn. Atmos. Ocean* 21, 227-256.
- [6] Klinger, B., J. Marshall, and U. Send. 1996: Representation of convective plumes by vertical adjustment, *JGR*, 101(C8), 18,175-18,182.
- [7] Legg, S., and J. Marshall. 1993: A heton model of the spreading phase of open-ocean deep convection, *J. Phys. Oceanogr.* 23, 1041-1056.
- [8] Marshall, J., J. A Whitehead, and T. Yates. 1994: Laboratory and numerical experiments in oceanic convection. *Ocean Processes in Climate Dynamics: Global and Mediterranean Examples*, edited by P. Malanotte-Rizzoli and A. Robinson, Kluwer Academic Publishers, pp. 437.
- [9] Marshall, J., C. Hill, L. Perelman, and A. Adcroft. 1997: Hydrostatic, quasi hydrostatic, and nonhydrostatic ocean modeling, *J. Geophysical Res.*, 102(C3), 5733-5752.
- [10] Marshall, J., A. Adcroft, C. Hill, and L. Perelman. 1997: A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers, *J. Geophysical Res.*, 102(C3), 5753-5766.
- [11] Marshall, J., and F. Schott. 1998: Open ocean deep convection: observations, models and theory: to appear, *Reviews of Geophysics*.
- [12] Marshall et al.: the Lab Sea Group. 1998: The Labrador Sea Deep Convection Experiment, October issue of *Bulletin of AMS*.
- [13] Send, U., and J. C. Marshall. 1995: Integral effects of deep convection, *J. Phys. Oceanogr.* 25, 855-872.
- [14] Visbeck, M., J. Marshall, and H. Jones. 1996: Dynamics of isolated convective regimes in the ocean, *JPO*, 26, (9), 1721-1734.
- [15] Visbeck, M., J. Marshall, T. Haine, and M. Spall. 1996: Specification of eddy transfer coefficients in coarse-resolution ocean circulation models, *J. Phys. Oceanogr.*, 27(3), 381-402.
- [16] Whitehead, J., J. Marshall, and G. Hufford. 1996, Localized convection in rotating, stratified fluid, *JGR*, 101(C11), 25,705 – 25,721.

- [17] Willcox, J. S., Y. Zhang, J. Bellingham, and J. Marshall. 1996: AUV survey design applied to oceanic deep convection, *Oceans 96 MTS/IEEE, Ft. Lauderdale, Florida*, Vol. 2, pp. 949-954.